UNIT–I

ANALOG AND DIGITAL SIGNAL CONDITIONING

Signal Conditioning circuits and stages analog signal conditioning

Signal conditioning circuits are used to process the output signal from sensors of a measurement system to be suitable for the next stage of operation.

The functions of the signal conditioning circuits include the following:

1. Signal level and bias changes
2. Linearization
3. Conversions
4. Signal transmission
5. Interfacing
6. Filtering
7. Protection

1.Signal level and bias changes

This is the basic step of signal conditioning. Adjusting the signal level means, changing the magnitude of the signal and bias change means changing the zero value required by the next stage. This also includes amplification/attenuation. This is usually achieved by operational amplifiers

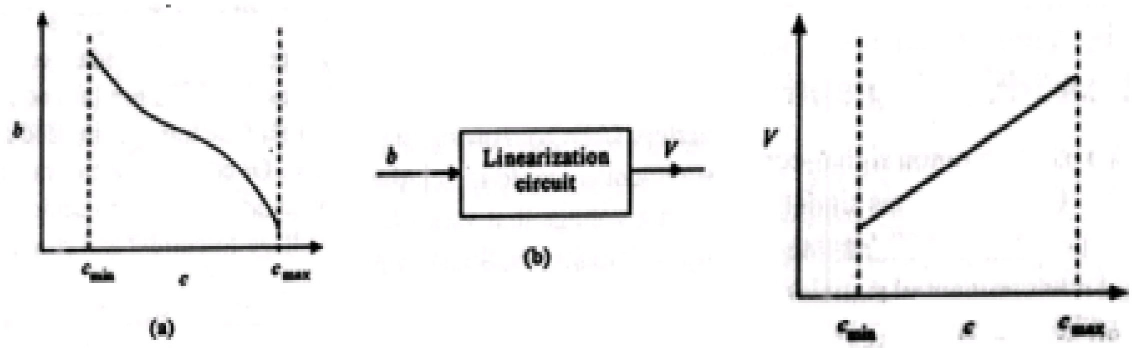
For example, if a sensor output voltage is from 0.1 to 0.5V and the required output is 0 to 5V, the first step is to make the output of the SCC to 0V for the sensor output of 0.1V. This can be done by subtracting 0.1V from the sensor output. Now the output of the sensor is 0 to 0.4V. As the required output is 0 to 5V, we have to multiply the input by 5/0.4=1.25. To make it happen, we need an amplifier. Here 1.25 is the gain of the amplifier, which is defined as the output /input.

Refer Table 1 for signal level and bias changes

S.No.	Function	Required Op-amp circuit
1	Addition	Summing amplifier
2.	Subtraction	Summing amplifier with one input +ve and other input -ve
3	Multiplication	Amplifier
4	Division	Attenuator

2.Linearization

Linearization is necessary when sensors produce voltage signals that are not linearly related to the physical measurement. The term linearization is the process of converting a nonlinear function to linear function. The purpose of linearization is to provide an output that varies linearly with input even if the sensor output is nonlinear



Input **Output**

3.Conversions

Converting one type of electrical variable to another. This usually carried out by bridge circuits and amplifiers.

<u>Example:</u>

Converting resistance to voltage, voltage to current, current to voltage etc. As RTD output is resistance, it should be converted in to voltage.

4.Signal transmission

An important type of conversion is associated with the process control is transmitting electrical signals in the form of current in the range 4-20mA. Current signals are used for signal transmission as it is independent of load variations. The signal from the transmission end (field), after transmission is converted in to voltage at the receiving end (control room).

5.Interfacing

For controlling a process we need computers. Computers only receive digital signal, so it need Analog to Digital Converters (ADC). For ADC the input requirement is usually 0-5V. So, signal transmitted in the form of current is to be converted in to voltage. For this current to voltage convertors are required.

6. Filtering and Impedance Matching

Usually signals are affected by noise and other unwanted disturbances. Often, spurious signals of considerable strength are present in the industrial environment, such as the 60-Hz line frequency signals. Motor start transients may also cause pulses and other unwanted signals in the process-control loop. In many cases, it is necessary to use high-pass, low-pass, or notch filters to eliminate unwanted signals from the loop. To remove the disturbances, it is necessary to use passive filters using resistors, inductors and capacitors and active filters such as op-amps.

Impedance matching is an important element of signal conditioning when transducer internal impedance or line impedance can cause errors in measurement of a dynamic variable. Both active and passive networks are employed to provide such matching.

7. Concept of Loading

One of the most important concerns in analog signal conditioning is the loading of one circuit by another. This introduces uncertainty in the amplitude of a voltage as it is passed through the measurement process. If this voltage represents some process variable, then we have uncertainty in the value of the variable. Qualitatively, loading can be described as follows. Suppose the open-circuit output of some element is a voltage, say V_x , when the element input is some variable of value x. This element could be a sensor or some other part of the signal-conditioning circuit, such as a bridge circuit or amplifier. Open circuit means that nothing is connected to the output. Loading occurs when we connect something, a load, across the output, and the output voltage V_y of the element drops to some value, $V_y < V_x$. Different loads result in different drops. If loading is ignored, serious errors can occur in expected outputs of circuits and gains of amplifiers. This concept plays an important role in analog signal conditioning.

7.Protection

Signal conditioners protect the field circuits during short circuit. Otherwise, the faulty circuit may shut down the entire supply chain and could cause damage to the wiring. Signal conditioners offer short circuit protection for each circuit of the field device. So, if a single circuit fails, the other circuits will not be affected.

OP-AMP CIRCUITS IN INSTRUMENTATION

1. Inverting amplifier
2. Non inverting amplifier
3. Voltage follower
4. Comparator
5. Differential amplifier
6. Summing amplifier

1. Inverting amplifier

The basic diagram for the inverting operational amplifier circuit is given in fig.1

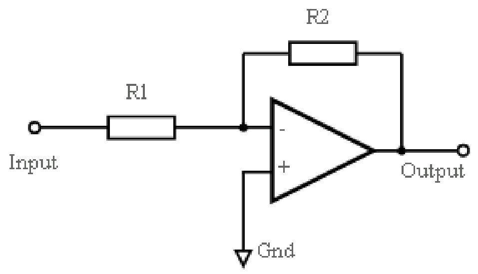


Fig.1 Inverting amplifier

The circuit consists of a resistor from the input terminal to the inverting input of the circuit, and another resistor connected from the output to the inverting input of the op-amp. The non inverting input is connected to ground. Here,

$$A_v = \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Where:

A_v is the voltage gain

R_2 is the feedback resistor value

R_1 is the input resistor value

V_{out} is the output voltage

V_{in} is the input voltage

2. Non inverting amplifier

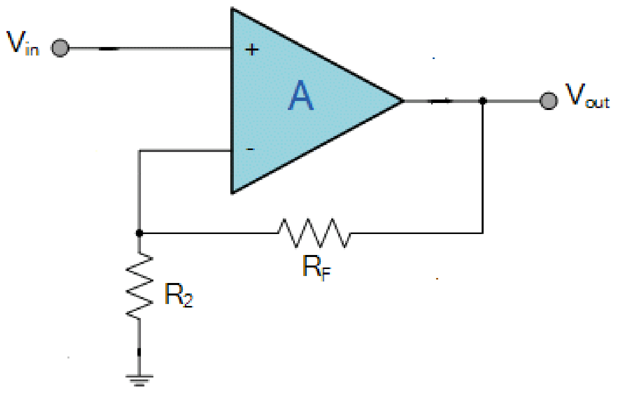


Fig.2 Non- Inverting amplifier

The basic diagram for the non inverting operational amplifier circuit is given in figure. In this configuration, the input voltage signal, (V_{in}) is applied directly to the non-inverting (+) input terminal which means that the output gain of the amplifier becomes “Positive”.

Here,

$$A_v = \frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_2}$$

Where:

A_v is the voltage gain

R_f is the feedback resistor value

R_2 is the input resistor value

V_{out} is the output voltage

V_{in} is the input voltage

3. Voltage follower

A voltage follower (also called a unity-gain amplifier, a buffer amplifier, and an isolation amplifier) is a op-amp circuit which has a voltage gain of 1. This means that the op-amp does not provide any amplification to the signal. This is called as voltage follower, because the output voltage directly follows the input voltage, meaning the output voltage is the same as the input voltage. Thus, for example, if 1V goes into the op-amp as input, 1V comes out as output. A voltage follower acts as a buffer, providing no amplification or attenuation to the signal. The basic diagram for the voltage follower circuit is given in fig.3.

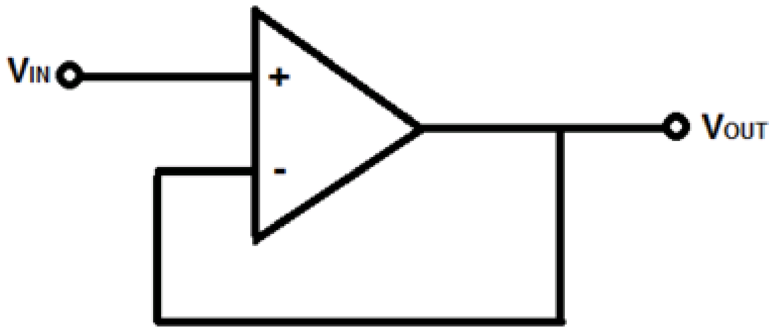


Fig.3 Voltage follower

For voltage follower

$$\boldsymbol{V_{out} = V_{in}}$$

Where:

V_{out} is the output voltage

V_{in} is the input voltage

4.Differential Amplifier:

Differential Amplifier is a device that is used to amplify the difference in voltage of the two input signals. Differential Amplifier is an important building block in integrated circuits of analog system. (Figure 4).

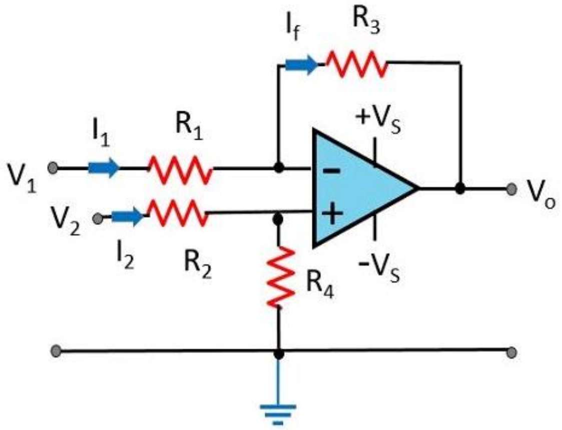


Figure 4, Differential Amplifier

When $R_1=R_2$

$R_3=R_f$

$$V_0 = -\frac{R_f}{R_1}(V_1 - V_2)$$

$$V_0 = \frac{R_f}{R_1}(V_2 - V_1)$$

5.Comparator:

The op-amp voltage comparator compares the magnitudes of two voltage inputs and determines which is the largest of the two.

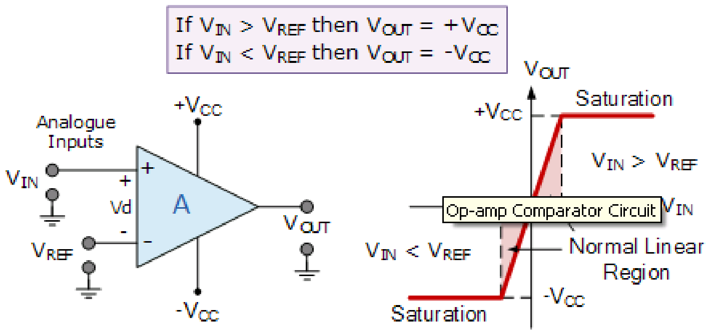


Figure 5. Comparator

6. Summing Amplifier:

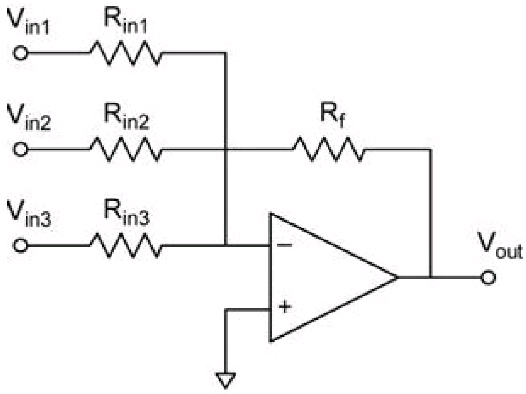


Figure 6. Summing Amplifier

The inverting amplifier circuit has only one voltage at the inverting input terminal. If more input voltages are connected to the inverting input terminal as shown in figure 6, the resulting output will be the sum of all the input voltages applied, but inverted. A circuit like this amplifies each input signal. The gain for each input is given by the ratio of the feedback resistor R_f to the input resistance in the respective branch.

$$V_{OUT} = - \{(R_f/R_{IN1})\, V_{IN1} + (R_f/R_{IN2})\, V_{IN2} + (R_f/R_{IN3})\, V_{IN3}\}$$

In a summing amplifier, if the input resistances are not equal, the circuit is called a Scaling Summing Amplifier.

If all the input resistances are chosen to be of equal magnitude (Rin), then the output equation of the summing amplifier can be rewritten as,

$$V_{OUT} = - \{(R_f/R_{IN})\, \{V_{IN1} + V_{IN2} + V_{IN3}\}$$

PASSIVE CIRCUITS

Bridge circuits

Bridge circuits are used primarily as an accurate means of measuring changes in impedance. Such circuits are particularly useful when the fractional changes in impedance are very small. Bridge circuits are used to convert impedance variations into voltage variations. One of the advantages of the bridge for this task is that it can be designed so the voltage produced varies around zero. This means that amplification can be used to increase the voltage level for increased sensitivity to variation of impedance.

Wheatstone Bridge

The simplest and most common bridge circuit is the DC Wheatstone bridge, as shown in Figure 7. This network is used in signal-conditioning applications where a sensor changes resistance with process variable changes. Many modifications of this basic bridge are employed for other specific applications. In Figure 7, the object labelled D is a voltage detector used to compare the potentials of points a and b of the network. In most modern applications, the detector is a very high-input impedance differential amplifier. In this case, the potential difference,ΔV , between points a and b is simply $\Delta V = V_a - V_b$

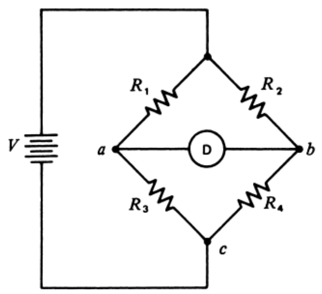


Figure 7. Wheatstone Bridge circuit

where V_a = potential of point a with respect to c

V_b = potential of point b with respect to c

The values of V_a and V_b now can be found by noting that V_a is just the supply voltage, V, divided between R_1 and R_3.

$$V_a = \frac{VR_3}{R_1 + R_3}$$

In a similar fashion, V_b is a divided voltage given by

$$V_b = \frac{VR_4}{R_2 + R_4}$$

where V = bridge supply voltage

As, $\Delta V = V_a - V_b$

$$\Delta V = \frac{VR_3}{R_1 + R_3} - \frac{VR_4}{R_2 + R_4}$$

Using algebra, the reader can show that this equation reduces to

$$\Delta V = V\frac{R_3R_2 - R_1R_4}{(R_1 + R_3)\cdot(R_2 + R_4)}$$

The above equation shows how the difference in potential across the detector is a function of the supply voltage and the values of the resistors. For making null, $\Delta V = V_a - V_b = 0$, and this can be achieved when, $R_3R_2 = R_1R_4$

Problem:

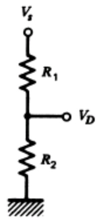
Find the value of R_4, if $R_1=1000\Omega$, $R_2=842\Omega$ and $R_3=500\Omega$, where R_1, R_2, R_3 and R_4 are the values of resistance of four arms of a Wheatstone bridge.

Solution:

$$R_1R_4 = R_3R_2$$
$$R_4 = \frac{R_3R_2}{R_1} = \frac{(500\ \Omega)(842\ \Omega)}{1000\ \Omega}$$
$$R_4 = \mathbf{421}\ \Omega$$

Divider Circuits

The voltage divider shown in Figure 8 can be used to provide conversion of resistance variation into a voltage variation.



The voltage of such a divider is given by the well-known relationship

$$V_D = \frac{R_2V_s}{R_1 + R_2}$$

where V_s = supply voltage
R_1, R_2 = divider resistors

Either R_1 or R_2 can be the sensor whose resistance varies with some measured variable.

Signal conditioning circuit.

The signal conditioning circuit is an electronic circuit that converts signals provided by a sensor to useful electric signals. These electric signals must meet specific criteria so that they are correctly interpreted and processed by the rest of the system's circuitry. The use of op-amps allows signal conditioning circuits to be more compact and precise in their implementations.

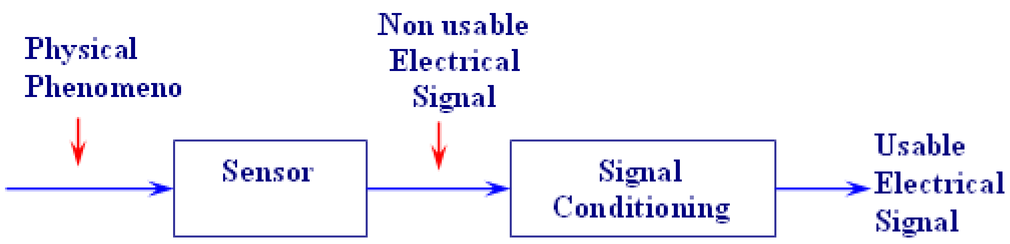


Fig. 1. Signal conditioning is important in a system of process control.

Signal conditioning carries out one or several of the following actions

1. **Change voltage level:** so that they are compatible with the following circuitry.
2. **Convert current to voltage:** Some sensors, such as the NTC (Negative Temperature Coefficient) and the PTC (Positive Temperature Coefficient) RTD (Resistance Temperature Dependent) convert the variations of the process to resistance variations. Signal conditioning circuits provide the necessary current that converts a resistance variation to an appropriate voltage.
3. **Convert the analog signal to digital signal:** The signal conditioning circuit ensures the analog signal which is at levels that are compatible with the analog to digital conversion circuitry. After having transformed the analog signals into digital, we can store their numerical representations on a memory, process them with an application program, display them on a monitor, send them through the Internet to another place, or print them.
4. **Convert the analog signal to current signal:** It is an industry standard that the control range is normalized from 4mA to 20mA dc. The minimum value of 4mA is defined as "zero active"because it offers the advantage of being able to detect an interruption of the connection between the sensor and the signal conditioning circuit. When the signal conditioning provides 0 mA at its output, it will be an indication that the sensor is defective or some other faulty circuit.
5. **Isolate the sensor:** The signal conditioning circuit should isolate the sensor electrically when the sensed signal contains high voltage pulses that can affect the measurements and the subsequent circuitry of the system.

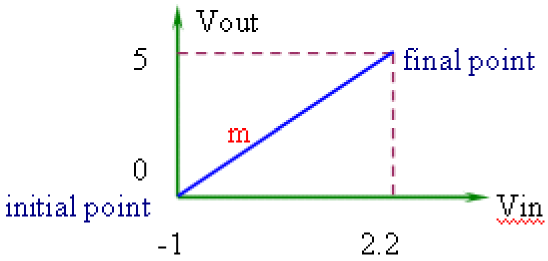
Problem:

The output of a process sensed by a sensor produces a voltage signal in the range of – 1 V to + 2.2 V . Build a circuit that converts the voltage to an output voltage of 0 to 5 V. Test your designs under different input voltages and verify your output voltages.

Solution

The input voltage (– 1 V to + 2.2 V) is the independent variable while the output voltage (0 to 5V) is the dependent variable.

By plotting the independent variable (x axis) and the dependent variable (y axis), we have:



Connect the intersection points, we find that the graph is a straight line, then:

$$V_{out} = mV_{in} + V_o \qquad \text{-----------------(1)}$$

(equation of the straight line; y = mx + C)

Where, m = slope, C = Constant,

Here it is called as bias voltage or offset voltage.

= (5-0) / (2.2-(-1)) =1.56

When Vin= -1V ; Vout=0V and

When Vin=2.2V; Vout=5V

Therefore 0 = m(-1) + Vo

5 = m(2.2) + Vo

Solving for m and Vo

m=1.56 and Vo = 1.56

From the values the output equation can be written as

Vout = 1.56Vin + 1.56 --------(2)

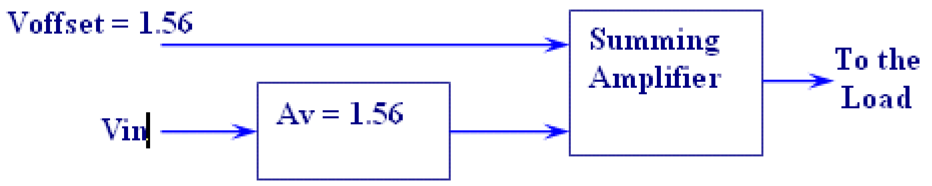
Then

Vout = Av (Vin) + Voffset ----------------------------(3)

Gain of the amplifier(Av)= 1.56 and

Voffset = 1.56V

Equation (2) indicates that we should use a circuit whose block diagram is



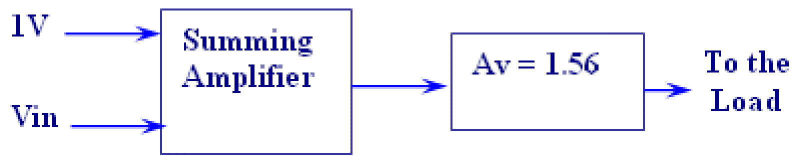
Replacing values, we have:

Vout = Av(Vin) + Voffset

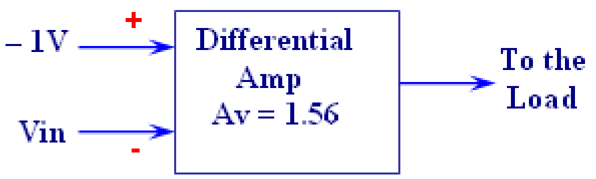
Vout = 1.56 (Vin) + 1.56

Vout = 1.56 (Vin + 1) -------------------- (4)

Equation (4) provides a second possible solution; the block diagram is shown below



The third possible solution comes from the previous circuit whose simplification is:



Note: In all the solutions, it is recommended to use an op-amp voltage follower between Vin and the input of the circuit. The purpose is to maintain impedance matching and prevent excessive loading of previous circuit stages.

The design of the problem statement will be accomplished by using solution 2. Figure shows the implementation of equation 4.

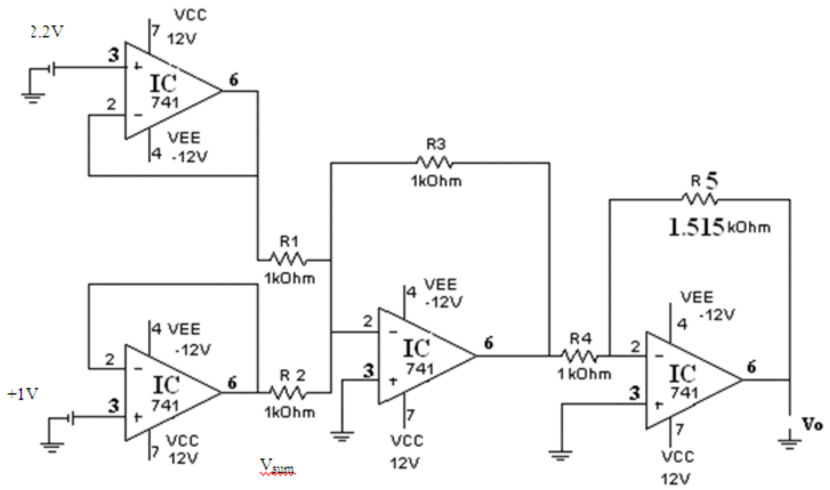


Fig. Circuit diagram

Problem:

A sensor outputs a voltage ranging from -2.4Vto-1.1V. For interface to an analog-todigital converter, this needs to be 0 to 2.5 V. Develop the required signal conditioning.

Solution:

$$V_{out} = mV_{in} + V_0$$

Using the specified information, we form two equations for the unknown slope (gain), m, and offset (bias), V_0.

$$0 = -2.4m + V_0$$
$$2.5 = -1.1m + V_0$$

Clearly, from the first equation we have $V_0 = 2.4m$, and when this is substituted into the second equation, we get

$$2.5 = -1.1m + 2.4m$$

Then, solving for m,

$$m = 2.5/(2.4 - 1.1) = 1.923$$

The transfer function equation is thus

$$V_{out} = 1.923\, V_{in} + 4.615$$

This can be accomplished by a differential amplifier.

$$V_{out} = 1.923(Vin + 2.4)$$

This is the equation of a differential amplifier with a gain of 1.923 and one input fixed at 2.4 V. A voltage follower would still be required on the input. To get 4.615V we can use a voltage divider . the circuit is shown in Figure.

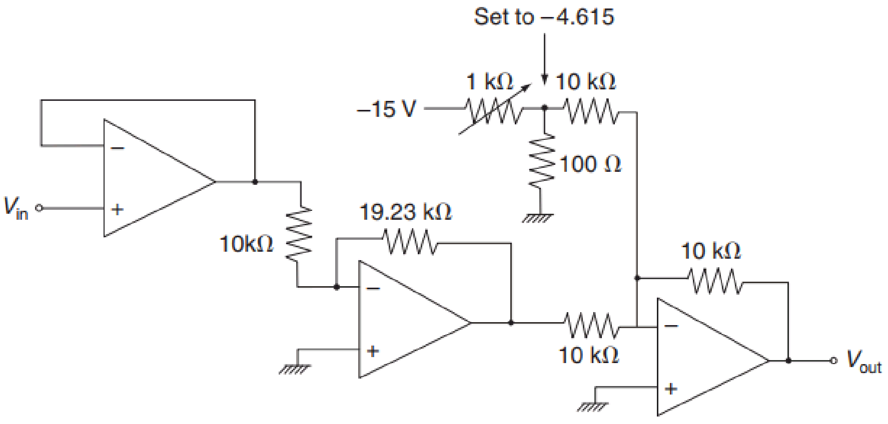


Figure: Circuit diagram

Problem:

Temperature is to be measured in the range of 250°C to 450°C . The sensor is a resistance that varies linearly from 280Ω to 1060Ω for this temperature range. Develop analog signal conditioning that provides a voltage varying linearly from -5 to +5 V for this temperature range.

Solution:

$$V_{out} = mR_s + V_0$$

We solve for m and V_0 by using the given information,

$$-5 = 280m + V_0$$
$$+5 = 1060m + V_0$$

Subtracting the first equation from the second gives

$$10 = 780m \quad \text{or} \quad m = 0.0128$$

Then, using this in the first equation,

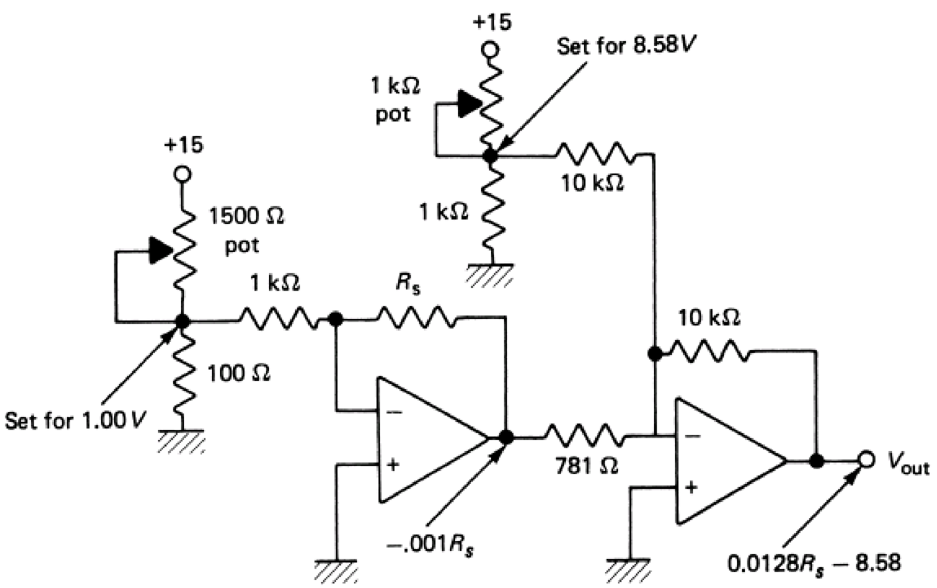
$$-5 = 280(0.0128) + V_0$$
$$V_0 = -8.58$$

So the transfer function equation is

$$V_{out} = 0.0128R_s - 8.58$$

This can be provided by an inverting amplifier with the sensor resistor in the feedback, followed by an inverting summer to get the signs correct.

Here 8.58V and 1V can be provided from divider circuits.



Problem:

Develop the required signal conditioning circuit for an analog to digital converter which needs and output of 0 to 2 V. The voltage available from the sensor is -1.1V to +1.5V.

Solution:

Equation for the output in terms of the input is

$$V_{out} = mV_{in} + V_0$$

We can form two equations for the unknown slope (gain), m, and offset (bias)

$0 = m(-1.1) + V_0$

$2 = m(1.5) + V_0$

$2=2.6m$

$m = 2/2.6$

$= 0.769$

$0=0.769(-1.1) +V_0$

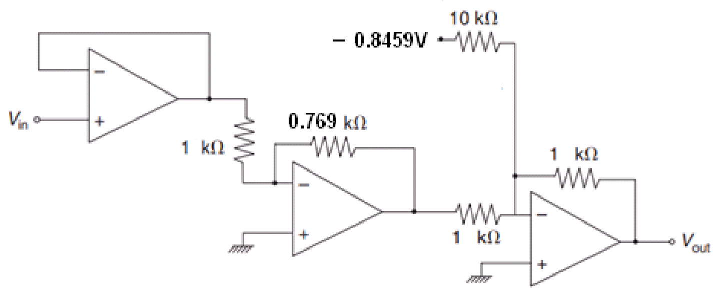
$0= - 0.8459 + V_0$

$V_0 = 0.8459.$

Now, the input output equation is

$V_{out} = 0.769V_{in} + 0.8459$

One possible solution is,



Problem:

Build a signal conditioning circuit for measuring level in a tank. The range of level is 0-8m and the sensitivity of the sensor is 0.5V/m. The required output is 4-20mA.

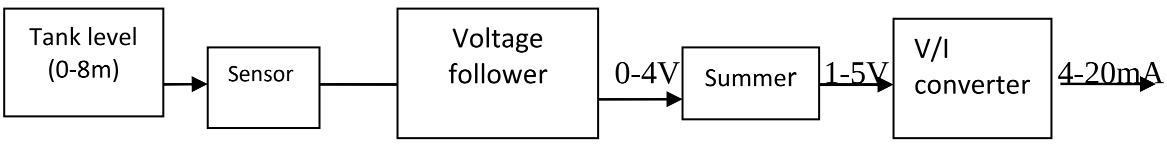
Solution:

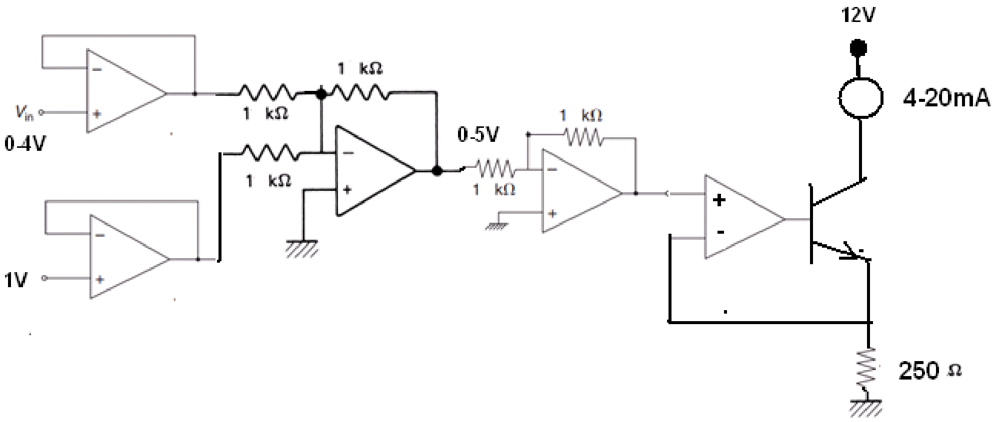
Sensitivity of the sensor= 0.5V/m

Range of level = 0 to 8m

For 10m, the sensor output = 8m x 0.5 V/m = 4V

Therefore range of sensor output = 0 – 4V





DIGITAL SIGNAL CONDITIONING

Computers are digital electronic devices and all the information they work with has to be digitally formatted. Therefore, if they are used to control a variable such as temperature, then the temperature has to be represented digitally. Hence, we need ADC and DAC for converting Analog signal to digital signals and digital signals to analog signals.

Digital-to-Analog Converters (DACs):

A DAC accepts digital information and transforms it into an analog voltage. The digital information is in the form of a binary number with some fixed number of digits. When used in connection with a computer, this binary number is called a binary ***word*** or computer word. The digits are called ***bits*** of the word.

The output of the DAC can be defined using Equation as a scaling of some reference voltage:

$$V_{out} = V_R[b_1 2^{-1} + b_2 2^{-2} + ... + b_n 2^{-n}]$$

Where, V_{out} = analog voltage output

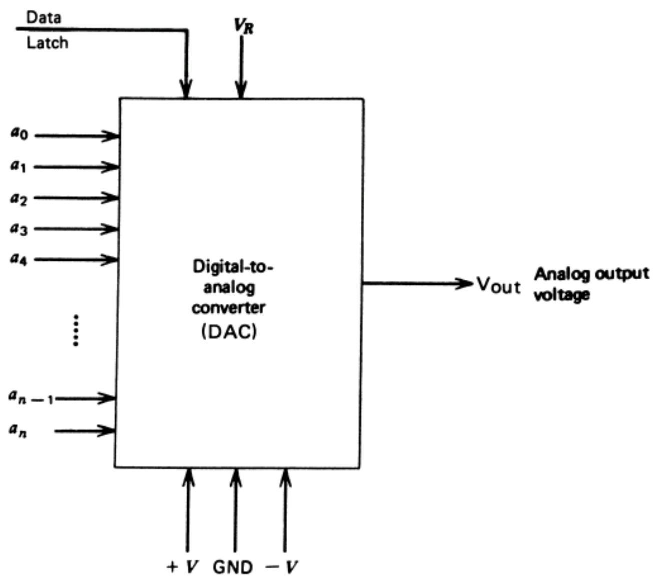
V_R = reference voltage

b_1, b_2 ... b_n = n-bit binary word

We can write

$$V_{out} = \frac{N}{2^n} V_R$$

Where, N = base 10 whole-number equivalent of DAC input



DAC Characteristics

Most DACs are integrated circuit (IC) assemblies, viewed as a black box having certain input and output characteristics. The above Figure, shows the essential elements of the DAC in terms of required input and output. The associated characteristics can be summarized as:

1. Digital input is a parallel binary word composed of a number of bits specified by the device specification sheet. TTL logic levels are usually required, unless otherwise noted.

2. The power supply is required for internal amplifiers. Some DACs operate from a single supply.

3. A reference supply is required to establish the range of output voltage and resolution of the converter.

4. The output is a voltage representing the digital input. This voltage changes in steps as the digital input changes by bits.

5. As the DAC is usually implemented with op amps, there may be the typical output offset voltage with a zero input. Typically, connections will be provided to facilitate a zeroing of the DAC output with a zero word input.

6. Many DACs have a data latch built into their inputs. When a logic command is given to latch data, whatever data are on the input bus will be latched into the DAC, and the analog output will be updated for that input data.

7. A DAC performs the conversion of digital input to analog output virtually instantaneously. The time taken by the DAC to convert digial signal to analog signal is called as conversion time.

Resolution of DAC:

Resolution is the number of possible output levels the DAC is designed to reproduce.

Problem:

A control valve has a linear variation of opening as the input voltage varies from 0 to 10 V. A microcomputer outputs an 8-bit word to control the valve opening using an 8-bit DAC to generate the valve voltage.

a. Find the reference voltage required to obtain a full open valve (10 V).

b. Find the percentage of valve opening for a 1-bit change in the input word.

<u>Solution:</u>

$$V_{out} = V_R(b_1 2^{-1} + b_2 2^{-2} + \cdots + b_8 2^{-8})$$

$$10 = V_R\left(\frac{1}{2} + \frac{1}{4} + \cdots + \frac{1}{256}\right)$$

$$V_R = \frac{10}{0.9961} = 10.039 \text{ V}$$

The percentage of valve change per step is found first from

$$\Delta V_{out} = V_R 2^{-8}$$

$$\Delta V_{out} = (10.039)\frac{1}{256}$$

$$\Delta V_{out} = 0.0392 \text{ V}$$

Thus,

$$\text{percent} = \frac{(0.0392)(100)}{10} = \mathbf{0.392\%}$$

Analog-to-Digital Converters (ADCs):

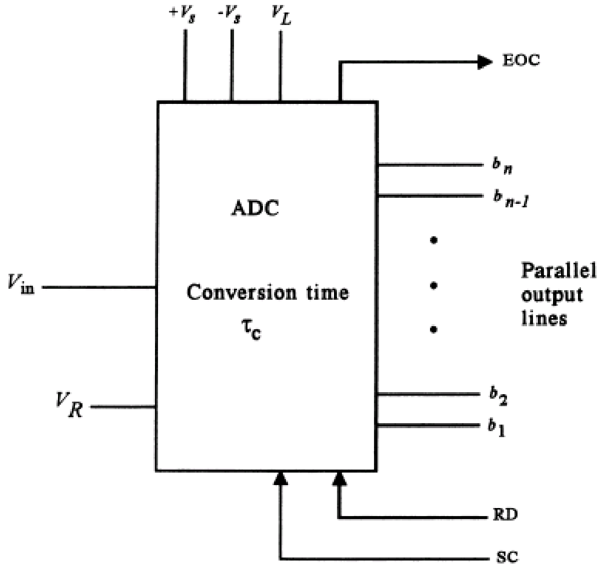
ADC provide a digitally encoded signal for the computer. The transfer function of the ADC can be expressed as

$$b_1 2^{-1} + b_2 2^{-2} + \cdots + b_n 2^{-n} \leq \frac{V_{in}}{V_R}$$

where $b_1 b_2 \ldots b_n$ = n-bit digital output
V_{in} = analog input voltage
V_R = analog reference voltage

And the difference between input and output, ΔV can be expressed as

$$\Delta V = V_R 2^{-n}$$



ADC Characteristics

The above Figure an ADC with all the connections. It is quite possible, and even appropriate in many cases, to regard the ADC as simply a black box with certain input and output characteristics. The following are the important characteristics of the ADC:

Analog voltage input : This is for connection of the voltage to be converted. This voltage should be constant during the conversion process.

Power supplies: Generally, an ADC requires bipolar supply voltages for internal op amps and a digital logic supply connection.

Reference voltage: The reference voltage must be from a stable, well-regulated source. Special, integrated circuit reference-source voltages are available for this purpose.

Digital outputs: The converter will have n output lines for connection to digital interface circuitry.

Control lines: The ADC has a number of control lines that are single-bit digital inputs and outputs designed to control operation of the ADC and allow for interface to a computer.

The most common lines are:

a. SC (Start-convert) is a digital input to the ADC that starts the converter on the process of finding the correct digital outputs for the given analog voltage input. Typically, conversion starts on a falling edge.

b. EOC (End-of-convert) is a digital output from the ADC to receiving equipment, such as a computer. Typically, this line will be high during the conversion process. When the conversion is complete, the line will go low. Thus, the falling edge indicates that the conversion is complete.

c. RD (Read): The receiving equipment must take the RD line low to enable and place the data on the output lines.

Conversion time

A typical ADC does not produce the digital output instantaneously when the analog voltage is applied to its input terminal. The ADC must sequence through a process to find the appropriate digital output, and this process takes time. The time taken by the ADC to produce a digital output for the analog input is called as conversion time.

Problem:

Temperature is measured by a sensor with an output of 0.02V/^{o}C . Determine the required ADC reference and word size to measure 0 to 100^{o}C with resolution 0.1^{o}C

Solution:

At the maximum temperature of 100^{o}C, the voltage output is

$$(0.02\ \text{V}/°\text{C})\,(100°\text{C}) = 2\ \text{V}$$

so a 2-V reference is used.

A change of 0.1°C results in a voltage change of

$$(0.1°\text{C})\,(0.02\ \text{V}/°\text{C}) = 2\ \text{mV}$$

so we need a word size where

$$0.002\ \text{V} = (2)\,(2^{-y})$$

$$y = \frac{\log(2) - \log(0.002)}{\log 2}$$

$$y = 9.996 \approx 10$$

so a **10**-bit word is required for this resolution. A 10-bit word has a resolution of

$$V = (2)\,(2^{-10})$$
$$V = 0.00195\ \text{V}$$

which is better than the minimum required resolution of 2 mV.

Notice that the output actually changes from $\mathbf{1111111110_2}$ to $\mathbf{1111111111_2}$ at a voltage of

$$V_R(1 - 2^{-n}) = (2\ \text{V})\,(1 - 2^{-10}) = 1.9980\ \text{V}$$

Problem:

Find the digital word that results from a 3.127-V input to a 5-bit ADC with a 5-V reference.

Solution:

$$b_1 2^{-1} + b_2 2^{-2} + \cdots + b_5 2^{-5} = \frac{3.127}{5} = 0.6254$$

Using the method of successive multiplication defined in Section 2.2, we find

$$\begin{aligned} 0.6254(2) &= 1.2508 \qquad \therefore b_1 = 1 \\ 0.2508(2) &= 0.5016 \qquad \therefore b_2 = 0 \\ 0.5016(2) &= 1.0032 \qquad \therefore b_3 = 1 \\ 0.0032(2) &= 0.0064 \qquad \therefore b_4 = 0 \\ 0.0064(2) &= 0.0128 \qquad \therefore b_5 = 0 \end{aligned}$$

so that the output is $\mathbf{10100_2}$.

Problem:

What is the output voltage of a 10-bit DAC with a 10.0-V reference if the input is 0010110101_2. What input is needed to get a 6.5-V output?

Solution:

$$\begin{aligned} V_{out} &= 10.0[2^{-3} + 2^{-5} + 2^{-6} + 2^{-8} + 2^{-10}] \\ V_{out} &= 10.0[0.1767578] \\ V_{out} &= 1.767578 \text{ V} \end{aligned}$$

To get the input needed to get 6.5V is

$$\begin{aligned} N &= 2^n(V_{out}/V_R) \\ N &= 1024(6.5/10) \\ N &= 665.6 \end{aligned}$$

is the DAC input.

Conversion Resolution :

The conversion resolution is a function of the reference voltage and the number of bits in the word.

$$\Delta V_{out} = V_R 2^{-n}$$

where ΔV_{out} = smallest output change
V_R = reference voltage
n = number of bits in the word

Problem:

Determine how many bits a D/A converter must have to provide output increments of 0.04 V or less. The reference is 10 V.

Solution:

$$\Delta V = 0.04 = (10)(2^{-y})$$

Taking logarithms

$$\log(0.04) = \log[(10)(2^{-y})]$$
$$\log(0.04) = \log(10) - y\log 2$$
$$y = \frac{\log(10) - \log(0.04)}{\log 2}$$
$$y = 7.966$$

Problem:

Develop a circuit to interface a temperature sensor and the ADC. The sensor outputs 6.5mV/^{o}C and it must measure 100^{o}C. A 6-bit ADC with a 10V reference is to be used. Also find the temperature resolution.

Solution:

To measure to 100°C means the sensor output at 100°C will be

(6.5 mV°C) (100°C) = 0.65 V

The interface circuit must provide a gain so that at 100°C the ADC output is 111111.

The input voltage that will provide this output is found from

$$V_x = V_R(a_1 2^{-1} + a_2 2^{-2} + \ldots + a_6 2^{-6})$$

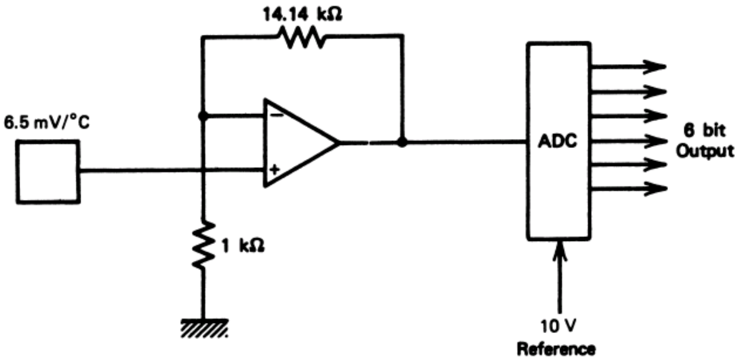
$$V_x = 10(1/2+1/4+1/8+ \ldots +1/64)$$

$$Vx = 9.84375 \text{ V}$$

Thus, the required gain must provide this voltage when the temperature is 100°C

Gain = 9.84375/0.65

= 15.14



The temperature resolution can be found by working backward from the least significant bit (LSB) voltage change of the ADC:

$\Delta V = V_R 2^{-n}$

$= 10\ (2^{-6}) = 0.15625\ V$

$\Delta V = 0.15625/15.4$

$=0.01032$

$\Delta T = 0.01032/0.0065 = 1.59^{o}C$ = Temperature Resolution

SAMPLE AND HOLD CIRCUIT(S/H Circuit)

The basic concept of the sample-and-hold circuit is shown in Figure, where the S/H is connected to the input of an ADC.

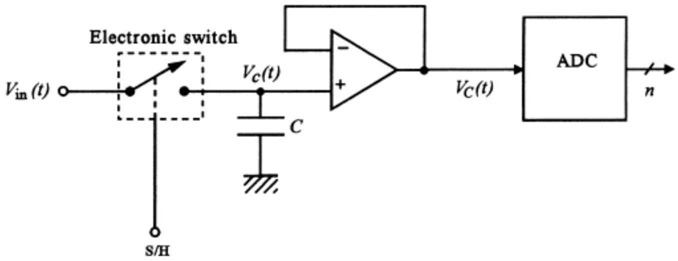


Figure: Sample and Hold circuit

When the switch is closed, the capacitor voltage will "track" the input voltage, $V_c(t) = V_{in}(t)$. At some time, t_s when a conversion of the input voltage is desired, the switch is opened and the capacitor is isolated from the input. Thus, the capacitor will hold the voltage when the switch opened, $V_c= V_{in}(t_s)$. The voltage follower allows this voltage to the ADC input, but the capacitor does not discharge because of the very high input impedance of the follower. The start-convert is then issued to ADC and the conversion proceeds with the input voltage remaining constant. When the conversion is complete, the switch is reclosed, and tracking continues until another conversion is needed. Figure shows how $V_{in}(t)$ and $V_c(t)$ would appear for a sinusoidal signal.

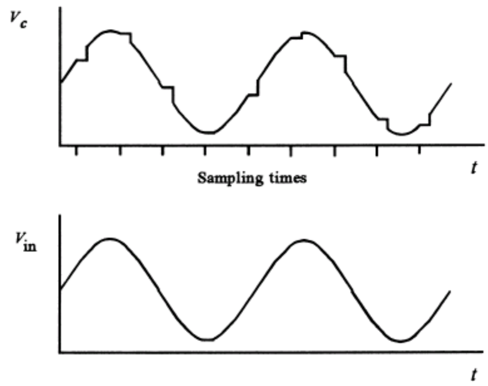


Figure: Input, output Signals of Sample and Hold circuit